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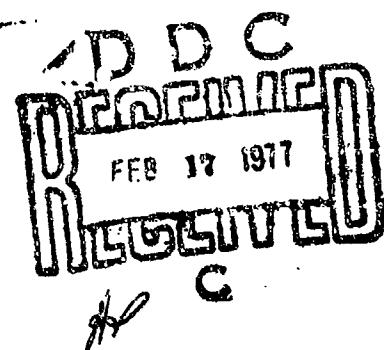
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DIELECTRIC CONSTANT AND LOSS DATA Part II

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DECEMBER 1975

TECHNICAL REPORT AFML-TR-74-250, Part II
INTERIM REPORT FOR PERIOD FEBRUARY 1972 - JANUARY 1975



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Project Engineer

FOR THE COMMANDER



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PREFACE

The dielectric constant and loss data presented in this report were measured at the Laboratory for Insulation Research of the Massachusetts Institute of Technology, Cambridge, Massachusetts, by W. B. Westphal. This work was performed between 1 Feb 1972 and 30 Dec 1974 under Contract F33615-71-C-1274, Project No. 7371, Task No. 737101, and Contract F33615-75-C-5020, Project No. 7371, Task No. 73710126, for the Air Force Materials Laboratory.

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The work was administered under direction of the AF Materials Laboratory, with Mr. D. J. Evans (AFML/PLJ) acting as project engineer.

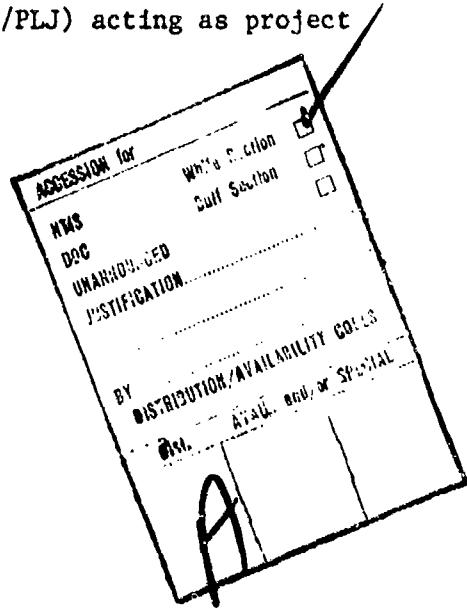


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I. INORGANIC COMPOUNDS

Aluminum oxides

Coors 96% Al_2O_3 ceramic

Coors

$T^{\circ}\text{C}$	$1000/T^{\circ}\text{K}$	Resistivity ρ (ohm-cm)
500	1.29	6.6×10^8
400	1.49	2.0×10^{10}
322	1.75	6.0×10^{11}
226	2.00	3.8×10^{13}
158	2.32	8×10^{14}
84	2.80	3×10^{16}
66.5	2.95	2×10^{17}
25	3.36	$1.5 \times 10^{18}^*$

* Extrapolated value, not measured.

Duramic HT-960, 96% Al_2O_3 ceramic

Duramic Products, Inc.

$T^{\circ}\text{C}$	Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^9	3×10^9
25	κ'	9.33	9.33	9.32	9.32	9.32	9.31	9.29	9.28
	κ''	.00393	.00293	.00182	.00191	.00182	.00233	.00668	.00526
	$10^4 \tan \delta$	4.2	3.1	1.95	2.05	1.95	2.5	7.1	5.6
	σ	2.18-13	1.63-12	1.01-11	1.06-10	1.01-9	1.23-8	3.71-6	8.75-6
100	κ'	9.43	9.43	9.42	9.41	9.41	9.40	9.37	
	κ''	.0113	.0063	.0044	.0036	.00272	.00243	.0073	
	$10^4 \tan \delta$	11.9	6.9	4.7	3.83	2.9	2.6	7.8	
	σ	6.25-13	3.6-12	2.46-11	2.0-10	1.51-9	1.28-8	4.05-6	
200	κ'	9.59	9.57	9.55	9.55	9.54	9.54	9.50	
	κ''	.0738	.0294	.0102	.0085	.0056	.0040	.0089	
	$10^4 \tan \delta$	76.9	30.8	10.7	8.96	3.9	4.2	9.4	
	σ	4.09-12	1.63-11	3.67-11	4.74-10	3.12-9	1.12-8	4.93-6	
300	κ'	10.42	9.93	9.79	9.72	9.69	9.68	9.63	
	κ''	.917	.246	.0759	.0263	.0147	.0103	.0112	
	$\tan \delta$	.088	.0247	.00775	.00271	.00132	.00106	.00116	
	σ	3.09-11	1.36-10	4.21-10	1.46-9	8.18-9	5.41-8	6.1-6	
400	κ'	13.26	10.79	10.12	9.96	9.87	9.85	9.79	
	κ''	3.43	1.32	.324	.0972	.0393	.0197	.0137	
	$\tan \delta$	.411	.1224	.0321	.00977	.0040	.0020	.00140	
	σ	3.03-10	7.34-10	1.8-9	5.4-9	2.19-8	1.04-7	7.6-6	
500	κ'	21.0	13.96	11.05	10.31	10.11	10.04	9.95	
	κ''	42.4	6.83	1.59	.387	.107	.038	.0172	
	$\tan \delta$	2.015	.489	.164	.0375	.0106	.0038	.00173	
	σ	2.39-9	3.73-9	8.83-9	2.14-8	5.93-8	2.7	9.55-6	

Aluminum oxides

Foam		Supplied by Rockwell International Corp.				
T° F		300 MHz	1 GHz	3 GHz	8.52 GHz	14 GHz
-300	κ	1.1171	1.11760	1.11560	1.11370	1.11150
	$\tan \delta$	.00015	.00015	.00015	.00007	.000005
-170	κ	1.1165	1.11680	1.11550	1.11320	1.11180
	$\tan \delta$	.00012	.00013	.00012	.00011	.00001
74	κ	1.11160	1.11630	1.11550	1.1160	1.11330
	$\tan \delta$	.00011	.00008	.00009	.00008	.000038
400	κ	1.1179	1.1180	1.11550	1.11550	1.11410
	$\tan \delta$	.00015	.00050	.00035	.00017	.0000015

Mullite, hot-pressed,
at 8.52 GHz

Air Force Materials Laboratory

	T°C	κ	$\tan \delta$
Dried in vacuum oven at 150°C	25	6.38	.00061
In equilibrium, room humidity	25	6.387	.0021
	98	6.37	.0029
	206	6.39	.0037
	313	6.37	.0052
	451	6.37	.0091
	575	6.41	.0103
	607	6.42	.0101
	746	6.43	.0095
	373	6.38	.0065
	28	6.38	.0020

Alumina cements

Green Refractories Co.

At 300 MHz, 25°C

Sample No.	κ	$\tan \delta$	Density (g/cm ³)	Sample No.	κ	$\tan \delta$	Density (g/cm ³)
1	6.31	.0089	2.707	26	6.24	.0113	2.567
2	6.19	.0109	2.608	27	6.42	.0119	2.629
3	6.14	.0110	2.566	28	6.35	.0108	2.622
25	6.02	.0116	2.453	29	6.58	.0096	2.736

Castolast G at 300 MHz, 25°C

Harbison-Walker Refractories

Sample No.	κ	$\tan \delta$	Density (g/cm ³)	κ	$\tan \delta$	Density (g/cm ³)
R-1	6.87	.0080	2.691	I-2	6.79	.0073
R-2	6.75	.0103	2.682	I-3	6.75	.0075
R-3	6.66	.0096	2.665	I-4	6.59	.0073
I-1	6.83	.0070	2.678	I-5	6.79	.0077

Alumina cements, at 300 MHz

Kaiser Refractories

Sample No.	Drying T° F	κ	$\tan \delta$	Density (g/cm ³)
3-8	260	7.07	.0073	2.819
4-7	400	6.27	.0063	2.734
5-7	600	6.25	.0062	2.719
5-6	800	5.95	.0050	2.644
20-1	600	5.78	.0096	2.584
11-1	600	6.22	.0072	2.742
19-5	600	5.97	.0072	2.666

Beryllium oxide plus silicon-nitride ceramic

National Beryllia Corp.

Niberlox, at 8.5 GHz, 25°C

		κ	$\tan \delta$	κ	$\tan \delta$	κ	$\tan \delta$
No. 5	Face 1	7.23	.00124	7.18	.00115		
	2	7.24	.00120	7.18	.00116		
	Average					7.20	.0012
No. 20	Face 1	7.37	.00162	7.32	.00115		
	2	7.36	.00170	7.32	.00114		
	Average					7.34	.0014
No. 100	Face 1	7.94	.00339	7.77	.00355		
	2	7.93	.00170	7.82	.00284		
	Average					7.88	.0030

Niberlox 5, at 8.5 GHz

T°C	κ	$\tan \delta$
25	7.29	.00115
132	7.40	.0011
207	7.46	.0011
314	7.56	.0012
494	7.72	.0014
588	7.80	.0015
704	7.91	.0024
781	8.00	.0035
900	8.08	.0046
1002	8.19	.0060

Boron nitride, hot-pressed,
with BN fibers, at 8.5 GHz

Carborundum

Sample Fc	T°C	
1	25	3.331 .00015 ± .00006
1, reversed		3.314 .00014
2		3.323 .00006
2, reversed		3.330 .00008
1 + 2 stacked		3.330 .000115 ± .00002
1 + 2 reversed	↓	3.321 .000125 ↓
1 + 2	100	3.33* .000111 ± .00005
	201	.000107
	300	.00015
	373	.00018
	421	.00017
	501	.00019
	600	.00021
	711	.00024
	800	.00038
	31	.00009

* Limit of error -.01, + 0.5.

Yarn and matrix,

Philco-Ford

Sample BN-3DX-V, at 8.5 GHz

	Face 1	κ	tan δ	Face 2		
				T°C	κ	tan δ
25°C, as received,	Face 1	2.862	.00293	25	2.88	.00015
	Face 2	2.897	.00334	200	2.89	.00011
vacuum dried,	Face 1	2.871	.00012	400	2.88	.00020
	Face 2	2.898	.00015	600	2.87	.00006
				800	2.87	.00011
				1000	2.89	.00072
				80	2.88	.00007

Cadmium telluride

IRTRAN 6, at 8.52 GHz, 24°C

Eastman Kodak

$$\begin{array}{lll} \kappa & \tan \delta & \sigma [\text{ohm-cm}]^{-1} \\ 10.45 \pm .03 & .024 \pm .004 & 1.18 \times 10^{-3} \end{array}$$

Ferrites

Emerson & Cuming, Inc.

E&C Samples A & S

Sample A

Frequency, MHz	μ'/μ_0	μ''/μ_0	ϵ'/ϵ_0	ϵ''/ϵ_0
1			13.8	.482
18	49.7	44	13.2	.231
55	16.8	30.2	-	-
80	12.8	22.7	-	-
189	12.24	36.6	-	-
300	3.17	26.0	13.01	.195
350	2.93	22.37	-	-
510	1.246	10.17	-	-
580	.905	9.02	-	-
650	.813	8.55	-	-
1000	- .234	7.67	12.34	-

Sample B

1	-	-	13.3	.427
18	51.	78.	13.2	.171
55	12.0	32	-	-
80	-	-	-	-
189	-	-	-	-
300	2.39	23.2	13.36	.116
350	-	-	-	-
510	-	-	-	-
580	-	-	-	-
650	.800	8.16	-	-
1000	- .336	7.64	13.28	<.02

Magnesium fluoride, hot-pressed
INTRAN 1

Eastman Kodak

$T^{\circ}C$	κ'	10^2	10^3	10^4	10^5	10^6	10^7	4×10^7	8.5×10^9
25	κ'	5.31	5.31	5.31	5.31	5.30	5.30	5.28	5.15
	$10^4 \kappa''$	4.8	4.5	3.2	2.0	2.5	1.6	8.5	12.1
	$10^4 \tan \delta$	.89	.84	.6	.38	.47	.5	1.6	2.3
	σ	2.7E-14	2.5E-13	1.8E-12	1.1E-11	1.4E-10	1.4E-9	2.1E-6	5.4E-6
100	κ'	5.40	5.38	5.36	5.34	5.33	5.33	5.35	
	$10^4 \kappa''$	6.05	8.89	7.86	4.89	4.3	4.8	9.1	
	$10^4 \tan \delta$	1.12	1.65	1.46	.92	.8	.9	1.7	
	σ	3.3E-14	4.9E-13	4.4E-12	2.7E-11	2.4E-10	2.7E-9	2.1E-6	
200	κ'	5.52	5.45	5.45	5.44	5.44	5.43	5.47	
	$10^4 \kappa''$	30.8	17.4	14.3	9.76	6.73	6.0	10.9	
	$10^4 \tan \delta$	5.57	3.19	2.62	1.80	1.22	1.1	2.0	
	σ	1.7E-13	9.6E-13	7.9E-12	5.4E-11	3.7E-10	3.3E-9	2.6E-6	
300	κ'	5.69	5.65	5.65	5.63	5.63	5.61	5.59	
	$10^4 \kappa''$	293	107	46.7	23.3	12.6	9.0	15.7	
	$10^4 \tan \delta$	51.8	18.9	8.26	4.14	2.23	1.6	2.8	
	σ	1.6E-12	6.E-12	2.6E-11	1.3E-10	7.E-10	5.E-9	3.7E-6	
400	κ'	5.85	5.79	5.77	5.76	5.75	5.74	5.72	
	κ''	.149	.034	.0114	.00536	.00276	.00172	22.9	
	$10^4 \tan \delta$	25.4	58.8	19.7	9.31	4.80	3.0	4.0	
	σ	8.3E-12	1.9E-11	6.3E-11	3.E-10	1.5E-9	9.5E-9	5.4E-6	
500	κ'	7.06	6.21	5.99	5.95	5.93	5.91	5.87	
	κ''	10.86	1.29	.202	.0337	.0105	.0067	.0031	
	$\tan \delta$	1.538	.209	.0339	.00566	.00177	.00113	.00053	
	σ	6.E-10	7.2E-10	1.1E-9	1.9E-9	5.9E-9	3.7E-8	7.3E-6	
532	κ'							5.91	
	$10^4 \kappa''$							34.3	
	$10^4 \tan \delta$							5.8	
	σ							8.1E-6	
27	κ'	5.325	5.32	5.32	5.32	5.31	5.31		
	$10^4 \kappa''$	17.8	12.9	9.53	7.97	7.31	6.9		
	$10^4 \tan \delta$	3.35	2.42	1.79	1.50	1.38	1.3		
	σ	9.92E-14	7.2E-13	5.3E-12	4.4E-11	4.1E-10	3.8E-9		

Magnesium fluoride, hot-pressed

IRTRAN 1 (cont.)

Comparison of 4 samples at 8.5 GHz, 25°C

		κ'	$10^4 \tan \delta$
Sample 1	Face 1 up	5.276	2.3
	Face 2 up	5.275	2.2
Sample 2	Face 1 up	5.276	2.2
	Face 2 up	5.273	2.0
Sample 3	Face 1 up	5.272	2.4
	Face 2 up	5.274	2.0
Sample 4	Face 1 up	5.283	1.9
	Face 2 up	5.285	2.1

The upward face receives incident energy. Sample was reversed and rotated 90° for second measurement.

Measured density of sample 1 at 25°C: 3.171 g/cm³.

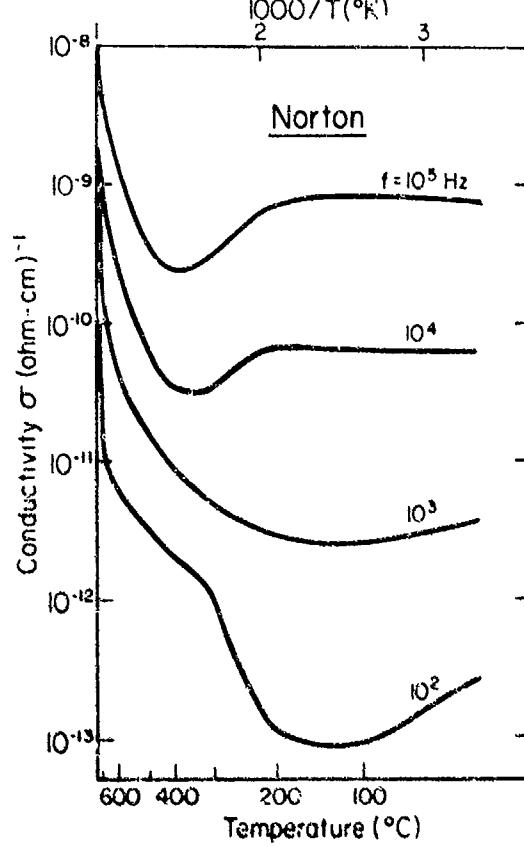
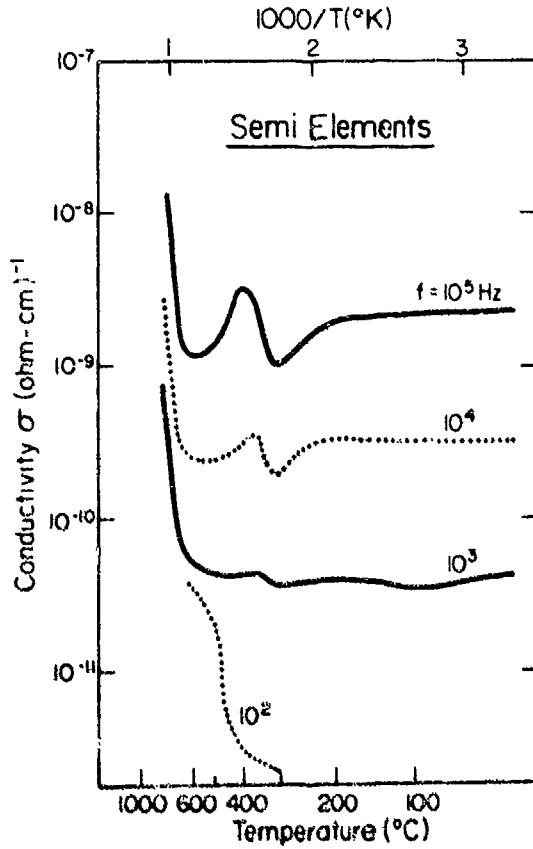
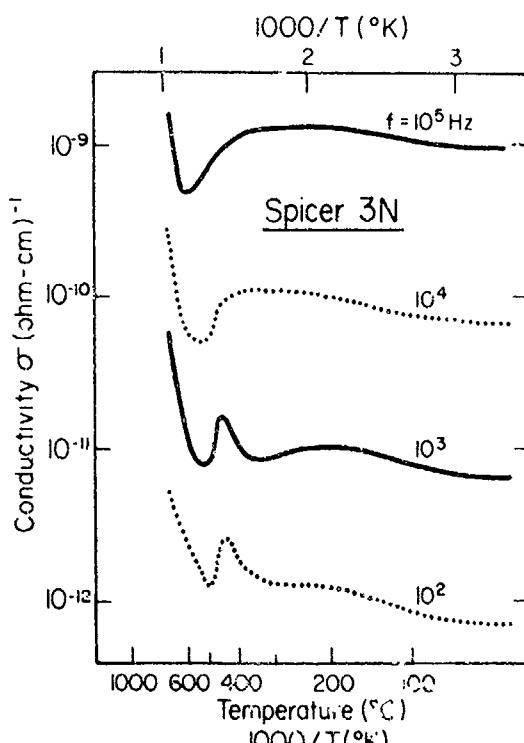
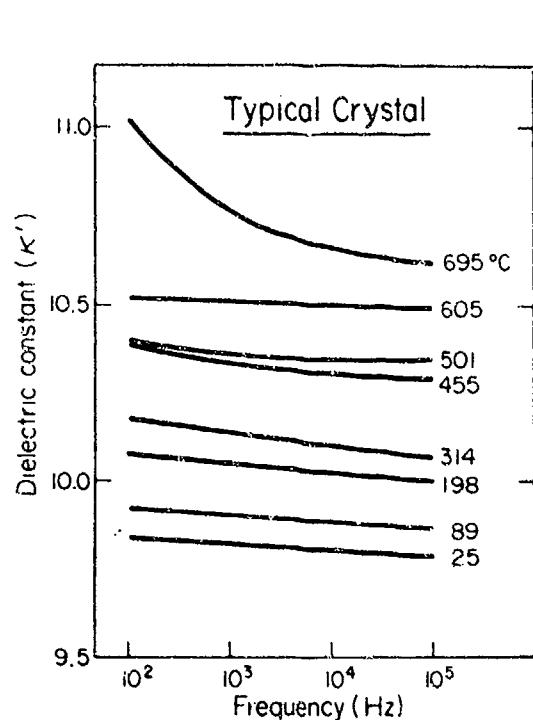
Magnesium oxide crystals

Chemical analysis of single crystals

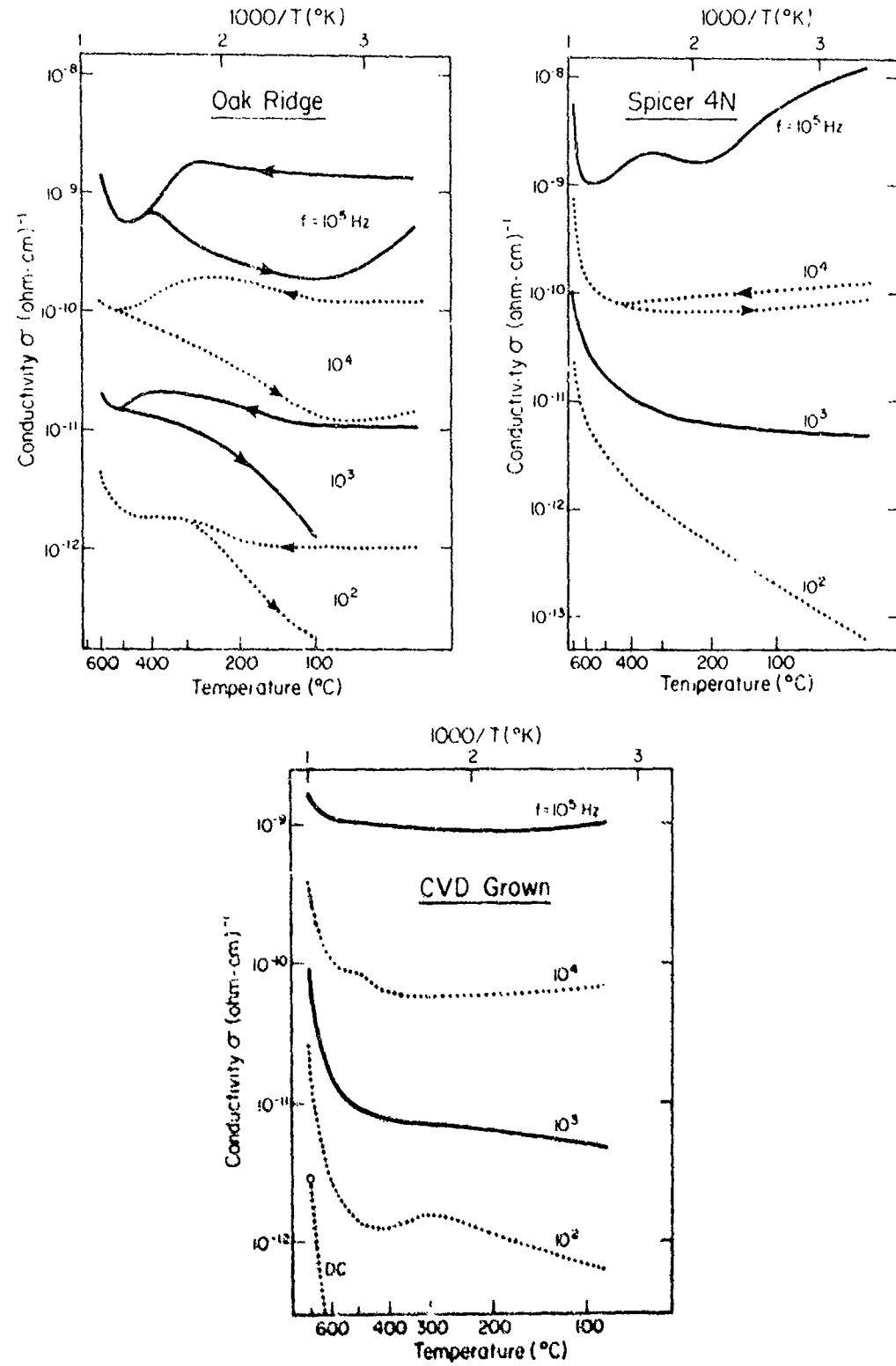
Department of Metallurgy,
Ceramics Laboratory, MIT

	Spicer 3-N	Semi- elements	Norton	Oak Ridge	Spicer 4-N	CVD
Al	70 ppm	10 ppm	10 ppm	10 ppm	10 ppm	100 ppm
Ca	100	50	50	5	5	1
Cr	-	-	10	-	-	10
Cu	5	10	10	5	10	10
Fe	20	50	50	10	50	10
Mn	10	10	5	10	-	-
Si	50	50	10	50	5	10
Zr	-	-	-	-	-	-
<u>Total</u>	<u>305</u>	<u>180</u>	<u>145</u>	<u>90</u>	<u>80</u>	<u>140</u>

Magnesium oxide crystals



Magnesium oxide crystals (cont.)



Cr-doped magnesium oxide

University of Colorado

Comparison of pure and Cr-doped magnesium oxide crystals

Dielectric constant (κ)

Sample	Freq., Hz	100	1 M
Pure		10.13	$10.16 \pm .15$
.068% Cr		-	$9.95 \pm .2$
.3% Cr		10.10	$10.07 \pm .3$

	L	W	T
Pure	1.045	.463	.222-.223
.068% Cr	.8818	.554-.563	.260-.281
.3% Cr	.980	.425-.458	.234

Note: Measurements limited in accuracy by irregular dimensions of samples.

Magnesium oxide

Eastman Kodak

IRTRAN 5, transparent ceramic

Density: 3.57 g/cm³

At 25°C

Freq., Hz	κ	$\tan \delta$
10^2	9.82	.0014
8.5×10^9	9.72	.00045

Spinel, hot-pressed

Coors' magnesium aluminatc ceramic , at 4.3 GHz Coors

T°F	κ_{meas}	$\tan \delta$
2	8.101	.00012 \pm .0005
34	8.119	
51.8	8.127	
61	8.135	
75.8	8.145 \pm .01	.00012 \pm .0003
96.2	8.155	
115.9	8.167	
133.2	8.179	
149.7	8.191	
184	8.217	
200.2	8.229	.00012 \pm .0005

At 76°F $\Delta\kappa/\Delta T = .00060^{\circ}\text{F}$.

Silica

Dynasil 4000 , at 3 GHz Dynasil

T°F	κ_{meas}	$\tan \delta$
2	3.8205	.00010
33	3.8212	
78	3.8225 \pm .005	.00010 \pm .00002
104.2	3.8232	
124.2	3.8237	
130.8	3.8240	
157.8	3.8245	
169	3.8250	
199.8	3.8261	.00010

At 78°F $\Delta\kappa/\Delta T = .0000268^{\circ}\text{F}$.

Note: The values of κ_{meas} included thermal dimension change effect.
The true dielectric constant κ_{corr} can be computed when thermal expansion linear coefficient (α) is known: $\kappa_{\text{corr}} = \kappa_{\text{meas}} / (1 + 2\alpha\Delta T)$.

Silica fiber + aluminum phosphate
Various experimental samples

Whittaker Corporation

(Density in g/cm ³)	Sample No. 14			Sample No. 15			Sample No. 16			Sample No. 17		
	T°C	K	tan δ	T°C	K	tan δ	T°C	K	tan δ	T°C	K	tan δ
After cutting	25	2.785	.001552	25	2.875	.00169	25	3.058	.00172	25	2.870	.00121
Oven dried	25	2.780	.00146	25	2.869	.00161	25	3.066	.00159	25	2.845	.00133
104	2.77	.00136	50	2.68	.00192	102	3.05	.00160	102	2.87	.00121	
202	2.76	.00131	103	2.88	.00138	208	3.06	.00143	200	2.88	.00140	
310	2.79	.00139	204	2.90	.00124	301	3.07	.00186	307	2.90	.00137	
407	2.86	.00147	302	2.90	.00118	399	3.08	.00201	399	2.91	.00161	
501	2.81	.00146	400	2.91	.00143	497	3.10	.00228	499	2.93	.00164	
620	2.82	.00150	495	2.92	.00154	600	3.11	.00216	605	2.94	.00167	
709	2.82	.00148	595	2.95	.00172	696	3.12	.00339	691	2.95	.00133	
800	2.86	.00136	639	2.96	.00221	797	3.13	.00439	800	2.97	.00408	
896	2.85	.00152	796	2.97	.00326	897	3.16	.00760	897	2.99	.00575	
25	2.77	.00126	696	2.96	.00443	93	3.06	.00197	28	2.87	.00144	
			25	2.83	.00159	25	3.04	.00169				
(Density in g/cm ³)	Sample No. 18			Sample No. 19			Sample No. 20					
	T°C	K	tan δ	T°C	K	tan δ	T°C	K	tan δ			
After cutting	25	3.244	.000521	25	3.372	.00605	25	3.075	.00416			
Oven dried	25	3.246	.00449	25	3.388	.0057	25	3.089	.00409			
100	3.27	.00139	104	3.35	.0042	99	3.12	.00468				
200	3.30	.00336	201	3.37	.0054	199	3.17	.0060				
299	3.31	.0061	300	3.38	.0095	300	3.18	.0096				
400	3.30	.0104	404	3.39	.0161	403	3.19	.0166				
495	3.33	.0165	501	3.43	.0229	490	3.23	.0241				
597	3.35	.0310	601	3.48	.0498	600	3.28	.0419				
697	3.38	.0565	699	3.54	.113	699	3.31	.077				
798	3.40	.0933	799	3.59	.220	800	3.34	.120				
899	2.62	.161	897	3.22	.797	896	3.40	.228				
25	3.31	.0667	25	3.37	.0054	25	3.16	.00425				

Silica fiber AS-3DX

Philco-Ford

		Sample, as received, 25°C		1 GHz		3 GHz	
		K	tan δ	K	tan δ		
5ZD-1	Face 1	3.130	.00794	3.049	.00826		
	Face 2	3.046	.00765			3.051	.00836
2	Face 1	3.001	.00176	2.976	.00183		
	Face 2	2.973	.00189			2.964	.00202
3	Face 1	3.159	.00815	3.118	.00850		
	Face 2	3.135	.00812			3.106	.00792
4	Face 1	3.031	.00159	3.005	.00212		
		3.007	.00151			2.997	.00187

5ZD-1

	After oven drying	T°C	1 GHz		3 GHz	
			K	tan δ	K	tan δ
Ambient	Face 1	25	3.025	.00192	3.013	.00235
		25	2.991	.00238	3.010	.00283
	Face 1	25	3.025	.00424	2.960	.00479
		25	2.966	.00434	2.985	.00458
	Face 1	119	3.047	.00236	3.046	.0032
		215	3.022	.00102	3.025	.00110
	Face 1	305	3.005	.00105	3.012	.00095
		401	3.003	.00123	3.010	.00108
	Face 1	500	3.001	.00163	3.007	.00126
		55	3.008	.00114	3.014	.00150

Silica fiber AS-3DX (cont.)

Sample 5ZD-2		1 GHz			3 GHz	
		T°C	κ	tan δ	κ	tan δ
After oven drying	Face 1	25	2.950	.00068	2.957	.00093
	Face 2	25	2.993	.00095	2.938	.00131
In H.T. holder	Face 1	25	2.949	.00103	2.953	.00119
		101	2.961	.00085	2.958	.00099
		211	2.955	.00078	2.960	.00086
		301	2.954	.00102	2.962	.00085
		403	2.955	.00115	2.960	.00104
		499	2.956	.00136	2.965	.00116
		19	2.950	.00086	2.955	.00097
Sample		8.52 GHz				
		T°C	κ	tan δ		
5ZD-5	Face 1, as received	25	3.131	.00706		
	Face 2, " "	25	3.127	.00600		
6	Face 1, " "	25	3.068	.00198		
	Face 2, " "	25	3.074	.00195		
5	Face 1, dried	25	3.071	.00115		
	Face 1, ambient	25	3.074	.00332		
		38	3.072	.00329		
		130	3.061	.00092		
		160	3.056	.00078		
		212	3.054	.00057		
		265	3.049	.00057		
		317	3.045	.00065		
		373	3.047	.00067		
		433	3.053	.00070		
		28	3.071	.00086		

Silica fiber AS-3DX (cont.)

<u>Sample</u>	8.52 GHz		
	T°C	K	tan δ
5ZD-5 Ambient	25	3.076	.00353
	344	3.041	.00054
	503	3.038	.00060
	604	3.036	.00090
	697	3.033	.00101
	793	3.028	.00124
	22	3.059	.00052
5ZD-6 Oven dried, Face 1 Face 2 In H.T. holder, Face 1	25	3.049	.00074
	25	3.053	.00077
	25	3.050	.00112
	139	3.050	.00112
	198	3.041	.00051
	313	3.039	.00056
	400	3.035	.00064
	501	3.037	.00074
	609	3.029	.00090
	694	3.026	.00106
	771	3.025	.00123
	22	3.044	.00035
5ZD-7		14 GHz	
As received, Face 1 rotated 90°	25	3.082	.0129
	25	3.083	.0117
As received, Face 2 rotated 90°	25	3.104	.0069
	25	3.096	.0071
Oven dried, Face 1 rotated 90°	25	3.038	.0044
	25	3.040	.0040

Silica fiber AS-3DX (cont.)

<u>Sample</u>		14 GHz	
	T°C	K	tan δ
5ZD-8			
As received, Face 1	25	2.983	.0058
rotated 90°	25	2.979	.0071
As received, Face 2	25	2.973	.0034
rotated 90°	25	2.950	.0034
Oven dried, Face 1	25	2.950	.00121
rotated 90°	25	2.948	.00148
	25	2.95	.00096
	112	2.95	.00062
	201	2.94	.00058
	296	2.95	.00061
	370	2.94	.00069
	482	2.94	.00105
	511	2.95	.00112
	50	2.95	.00052
5ZD-9		24 GHz	
As received, Face 1	25	3.116	.01127
rotated 90°	25	3.111	.01155
Oven dried, Face 1	25	3.085	.00358
rotated 90°	25	3.081	.00348
Redried, Face 1	25	3.082	.00321
In H.T. holder	25	3.083	.00425
	110	3.08	.00354
	197	3.07	.00178
	309	3.06	.00197
	408	3.06	.00150
	492	3.05	.00117
	584	3.04	.00093
	676	3.04	.00132
	797	3.03	.00131
	18	3.04	.00071

Silica fiber AS-3DX (cont.)

<u>Sample</u>	24 GHz		
	T°C	κ	tan δ
5ZD-10			
As received, Face 1	25	3.013	.00317
rotated 90°	25	3.006	.00305
Oven dried, Face 1	25	2.987	.00099
rotated 90°	25	2.999	.00113
Redried, Face 1			
In H.T. holder	25	3.000	.00154
	99	3.002	.00118
	204	3.00	.00064
	289	3.00	.00061
	380	2.99	.00068
	481	2.99	.00064
	598	2.99	.00079
	680	2.99	.00093
	799	2.98	.00128
	17	2.999	.00079

Silica fiber, silicone coated

Raytheon Co.

At 8.5 GHz					
<u>As received</u>		Sample F		Sample G	
		κ	tan δ	κ	tan δ
Face 1	min	3.173	.00568	2.966	.00268
	max	3.190	.00557	2.979	.00270
Face 2	min	3.185	.00585	2.987	.00279
	max	3.176	.00601	3.000	.00271
<u>After 24 hrs. 100°C, vac. oven</u>					
Face 1		3.160	.00431	2.985	.00230
Face 2		3.150	.00425	2.990	.00232

Silicates

Borosilicate coating	Supplied by Rockwell International Corp.
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	T°C	8.52 GHz	14 GHz
-300	K	2.35	2.30
	tan δ	.0030	.0030
-170	K	2.40	2.35
	tan δ	.0050	.0050
74	K	2.45	2.40
	tan δ	.01630	.0160
400	K	2.50	2.45
	tan δ	.0180	.0200

Corning 7971 Glass

Corning

At 4 GHz

T°F	K _{meas}	tan δ
4	4.01156	.00014 ± .00003
10.6	4.011182	↓
77.7	4.01456 ± .003	.00015 ± .00003
94.2	4.01530	
111.2	4.01577	
127.5	4.01693	
143.2	4.01740	
159.4	4.01777	
173.3	4.01882	
182.1	4.01935	
192.3	4.01982	
226.1	4.02051	.00016 ± .00003

Note: The values of K_{meas} included thermal dimension change effect.
 The true dielectric constant K_{corr} can be computed when thermal expansion linear coefficient (α) is known: $K_{corr} = K_{meas}/(1+2\alpha\Delta T)$.
 The temperature coefficient of dielectric constant $\Delta K_{meas}/\Delta T(T=78) = .0000377$, which compares favorably with the corresponding values for Corning 7940 fused silica and single-crystal spinel of .0000397 and .000702 respectively.

Silicates

Pennvernon glass

PPG Industries, Inc.

Resistivity in ohm-cm

T°C	60 Hz	1 kHz
21	6.5E10	8.63E9
50	1.7E10	4.03E9
75	6.2E9	1.87E9
100	2.60E9	8.14E8
125	7.8E8	3.65E8
150	2.02E8	1.45E8
175	6.08E7	5.18E7
200	1.88E7	1.78E7
225	6.55E6	6.40E6
250	2.74E6	2.57E6
275	1.20E6	1.12E6
300	5.24E5	5.12E5
325	2.58E5	2.50E5
350	1.43E5	1.37E5
Freq., Hz	60	1 k
K	8.41	7.74
P.F.	.059	.0302
		.0107

Float Glass

T°C	60 Hz		1 kHz		60 Hz		1 kHz	
	ρ	ρ	T°C	ρ	ρ	ρ	ρ	ρ
25	6.12E10	7.55E9	200	3.85E7	3.8E7			
50	3.2E10	4.9E9	225	1.33E7	1.33E7			
75	1.2E10	2.65E9	250	5.3E6	5.3E6			
100	4.8E9	1.22E9	275	2.15E6	2.15E6			
125	1.5E9	5.1E8	300	1.06E6	1.06E6			
150	3.8E8	2.17E8	325	4.75E5	4.75E5			
175	1.22E8	9.4E7	350	2.55E5	2.55E5			
			25°					
Freq., Hz		60		1 k			1 M	
K			8.38		7.87		7.05	
P.F.			.0596		.0302		.0110	

Silicates

P-18

PPG Industries, Inc.

T°C	60 Hz	1 kHz
25	5.30E10	7.44E9
50	1.87E10	3.31E9
75	6.34E9	1.56E9
100	2.02E9	6.55E8
125	4.92E8	2.57E8
150	1.18E8	8.09E7
175	3.28E7	3.10E7
200	1.04E7	1.04E7
225	3.68E6	3.68E6
250	1.47E6	1.47E6
275	6.36E5	6.36E5
300	2.90E5	2.90E5
325	1.42E5	1.42E5
350	7.32E4	7.32E4

Freq., Hz	60	1 k	1 M
κ'	8.62	7.96	7.49
P.F.	.0655	.0168	.0115

Silicon nitride ceramic

Raytheon Company

	T°C	κ	tan δ
As received	25	4.627, 4.637	.0035, .0028
Partially dried	25	4.606 - 4.613	.00187, .00175
In H.T. holder	25	4.61	.0024
	200	4.60	.0013
	419	4.61	.0011
	607	4.60	.0023
	713	4.62	.0043

Silicon nitride with MgO, hot-pressed Air Force Materials Laboratory

Experimental

At 14 GHz

	Thickness (cm)	T°C	k'	tan δ	k'	tan δ
Face 1	.381	25	8.286	.00699	8.26	.00756
Face 2	.381	25	8.289	.00780	8.24	.00793
Face 1	.279	25	8.285	.00645		
Face 2	.279	25	8.286	.00667		
Face 1	.270	108	8.28	.0070		
		197	8.30	.0062		
		308	8.33	.0065		
		403	8.34	.0072		
		494	8.35	.0083		

Silicon nitride, hot-pressed Air Force Materials Laboratory

with 3 w/o MgO + 5 w/o BN, experimental

At 14 GHz

	T°C	k	tan δ
Face 1	25	8.295	.0436
face 2	25	8.250	.0440
	98	8.27	.0413
	210	8.21	.0415
	299	8.22	.0418
	396	8.24	.0425
	500	8.36	.0431
	29	8.18	.0404

Zinc selenide

Eastman Kodak

IRTRAN 4, at 9.52 GHz, 24°C

k	tan δ	σ [ohm-cm] ⁻¹
10.08	.0063	3.0×10^{-4}

Zinc sulfide (95% sphalerite, 5% wurtzite)
IRTRAN 2, at 8.52 GHz, 24°C

Eastman Kodak

κ	$\tan \delta$	$\sigma [\text{ohm-cm}]^{-1}$
8.62	.00152	6.18×10^{-4}

II. MISCELLANEOUS INORGANICS

Gypsum board (sheet rock)
($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)

Supplied by The Sippican Corp.

	Freq., Hz	60	50 k	500 k	3 M	100 M
As received	κ	9.7	2.53	2.45	2.34	2.32
	$\tan \delta$	.92	.0805	.0225	.0125	.0088
Dried	κ	1.875	1.820	1.802	1.788	1.765
	$\tan \delta$	.0172	.00591	.00526	.0050	.0061

Shale rock

Supplied by Raytheon Company

Sample D, EH

$T^{\circ}\text{C}$	50 Hz			1 MHz			10 MHz		
	κ	$\tan \delta$	$T^{\circ}\text{C}$	κ	$\tan \delta$	$T^{\circ}\text{C}$	κ	$\tan \delta$	
19.5	417.	.810	19.5	10.3	.316	19.5	7.60	.209	
57	640.	.564	57	14.9	.486	57	9.38	.293	
82	540.	.710	74	17.54	.591	81	10.2	.429	
110	475.	1.27	114	20.4	.660	111	11.0	.435	
163	390.	1.17	134	20.9	.646	159	9.30	.554	
204	350.	1.31	157	19.9	.597	218	8.20	.264	
339	742.	4.75	224	11.9	.360	325	7.42	.213	
420	117.*	6.63*	259	10.7	.324	426	9.16	.100	
			308	10.5	.195				
			312	10.3	.197				
			432	11.2	.242				

*100 Hz.

Shale rock

Raytheon Company

Sample D, 3 GHz, E

T°C	κ	tan δ
25	5.12	.037
100	5.26	.055
200	5.27	.047
250	5.19	.036
299	4.94	.037
352	5.19	.050
400	5.40	.079
450	7.34	.049

Shale rock

Raytheon Company

Various samples, electric field
oriented with respect to laminar
structure

Sample/Field	Freq., Hz	50	1 M	10 M	30 M	100 M	300 M	1 G	3 G
A, E ||	κ	-	19.7	14.52	11.5	8.3	5.34	5.24	5.20
A, E ||	tan δ	-	.212	.257	.276	.309	.0182	.0174	.025
A, E ||	θ	3.39E5							
A, E ⊥	κ	9.30	6.37	5.92	5.85	5.80	-	-	-
A, E ⊥	tan δ	.171	.0255	.0217	.0181	.0142	-	-	-
B, E ||	κ	172	11.58	7.30	6.62	6.05	5.44	5.18	4.97
B, E ||	tan δ	.313	.463	.267	.180	.102	.108	.079	.049
B, E ⊥	κ	102	7.55	5.65	5.50	5.44	-	-	-
B, E ⊥	tan δ	.359	.237	.0937	.061	.040	-	-	-
D, E ||	κ	264	10.9	7.65	6.72	6.90	5.35	5.15	5.12
D, E ||	tan δ	2.60	.322	.219	.176	.130	.0917	.061	.037
D, E ⊥	κ	55.3	7.62	5.92	5.58	5.30	-	-	-
D, E ⊥	tan δ	.556	.236	.139	.140	.067	-	-	-

Shale rock, oil-rich
E //

Raytheon Company

Freq., Hz	50	1 M	10 M	30 M	100 M	300 M	1 G	3 G
κ	4.68	3.12	2.95	2.88	2.83	2.79	2.76	2.73
$\tan \delta$	.118	.0384	.0339	.0312	.0272	.0264	.0261	.0254

III. ORGANICS

Polyimide laminate AL-300

Atlantic Laminates

At 22°C

	3 GHz		8.5 GHz	
	κ	$\tan \delta$	κ	$\tan \delta$
Best value	4.48	.0132	4.412	.0137

Temperature run on stacked sample, 8.52 GHz

T°C	κ	$\tan \delta$	Sample thickness (cm)	Comments
23.5	4.16	.0097	.635	
98	4.30	.0104	.622	
198	4.41	.0116	.611	
284	4.50	.0116	.599	Smoke detectable
336	4.52	.0123	.597	Noticeably soft
426	4.01	.0142	.633	Smoking profusely
458	2.605	.0097	.824	too much smoke, gelatin-like softness, rapidly expanding
261	2.025	.0048	1.003	

Plastic ropes

Condex

At 25°C, electric field
parallel to sample axis

Frequencies		Condex Tri-Laminar	Condex Urethane	"Glastran" rope
100 kHz	κ	4.77	4.50	4.88
	$\tan \delta$	.043	.047	.0128
1 MHz	κ	4.51	4.22	4.80
	$\tan \delta$	.062	.060	.0167
10 MHz	κ	4.07	3.88	4.73
	$\tan \delta$	.061	.055	.020
100 MHz	κ	3.78	3.66	4.55
	$\tan \delta$	.067	.060	.026
1000 MHz (extra- polated)	κ	3.5	3.4	4.2
	$\tan \delta$	.076	.066	.034

Styrofoam FR

Dow-Corning

At 25°C

	Freq., GHz	κ	$\tan \delta$
2 Stacked coax at 1 and 3	1	1.0335	.00005
	3	1.0323	.000077
1 Cylinder	8.5	1.0372	.000109

Sylgard 188

Dow-Corning

	25°C		-55°C	
Freq., Hz	κ	$\tan \delta$	κ	$\tan \delta$
100	2.858	.00292	3.332	.00239
1000	2.854	.00198	3.330	.00271
1500	2.853	.00197	3.329	.00286
8000	2.849	.00191	3.327	.00329
10000	2.849	.00190	3.326	.00332
10^5	2.844	.00178	3.317	.00318
10^6	2.841	.00152	3.308	.00377
10^7	2.839	.00165	3.301	.00665

Silastics

Dow-Corning

Samples E-1600 140 at 8.52 GHz

	A		C	
T°C	κ	$\tan \delta$	T°C	κ
18	3.046	.0193	25	2.740
-8		.0234*	0	2.775
-19	3.128	.0204	-24	2.808
-40	3.118	.0117	-33	2.813
-77	3.091	.00653	-42	2.815
-195	3.126	.00598	-63	2.798
			-80	2.778
			-100	2.760
25	2.99	.0118	-130	2.758
			-151	2.767
			-195	2.791
				.00244
				.00256
				.00221

*Estimated value, not measured.

Silicone resin

Dow Corning

At 8.52 GHz, 22°C

<u>Material</u>	κ	$\tan \delta$
X-12546	3.381	.00768
XR-43117	2.885	.0176

Fiber samples

E. I. Du Pont de Nemours and Company

At 8.52 GHz

Sample No.	Orientation of electric field to surface fiber direction	T°C	κ	$\tan \delta$
5230-126	arbitrary,	75	3.83	.0530
	" , same	150	4.03	.0775
	" , same	300	4.15	.128
126	0°, E||	75	4.21	.0263
	90°, E⊥	75	3.45	.0263
5230-127	arbitrary,	75	3.64	.0286
	" , same	150	3.71	.035
	" , same	300	3.81	.063
127	0°, E||	75	3.96	.0236
	30°	75	3.83	.0238
	45°	75	3.55	.0232
	90°, E⊥	75	3.32	.0209
127	0°, E||	300	4.15	.055

Tedlar

E. I. Du Pont de Nemours and Company

At 25°C, 50% R.H.

Freq.	8.5 GHz	14 GHz	24 GHz
-	4.38	4.32	4.28
$\tan \delta$	.044	.0040	.035

"TEFLON" TFE 7A

E.I. Du Pont de Nemours & Company

T°C	Hz	100	1 k	10 k	100 k	1 M	10 M	100 M	300 M	1 G	3 G	8.5 G	14 G	24 G
250	κ	1.91	—	—	—	—	—	—	1.91	1.912	1.912	1.912	1.91	1.91
	$10^4 \tan \delta$	10.05	1.62	.60	.09	.14	<.1	—	.6	.3	1.3	2.3	2.8	3.3
150	κ	2.00	—	—	—	—	—	—	2.00	2.002	2.001	2.001	2.000	2.00
	$10^4 \tan \delta$	5.00	.69	.13	.08	.16	.23	—	1.0	1.3	3.2	2.7	3.9	3.5
23	κ	2.03	—	—	—	—	—	—	2.051	2.050	2.050	2.048	2.047	—
	$10^4 \tan \delta$	.06	.04	.04	.05	.13	.15	1.4	3.2	3.7	3.4	2.3	2.6	3.0

"TEFLON" PFA TE 9704

E.I. Du Pont de Nemours & Company

T°C	Hz	100	1 k	10 k	100 k	1 M	10 M	100 M	300 M	1 G	3 G	8.5 G	14 G	24 G
23	κ	2.06	—	—	—	—	—	—	—	2.060	2.058	2.055	2.052	2.049
	$10^4 \tan \delta$	.27	.20	.23	.35	.80	1.45	4.5	8.4	11.3	14.4	13.8	13.1	12.4
75	κ	—	—	—	—	—	—	—	—	2.043	2.041	2.038	2.034	2.034
	$10^4 \tan \delta$	—	—	—	—	—	—	—	—	11.0	14.0	14.7	14.5	14.1
100	κ	2.03	—	—	—	—	—	—	—	2.031	2.029	2.027	—	2.023
	$10^4 \tan \delta$	6.03	.91	.39	—	—	—	—	—	9.4	12.6	14.3	—	13.3
130	κ	2.01	—	—	—	—	—	—	—	2.010	2.009	2.007	2.004	2.002
	$10^4 \tan \delta$	28.6	3.96	.77	.40	.45	1.1	—	3.2	8.3	11.1	13.8	14.8	13.3
200	κ	—	—	—	—	—	—	—	—	1.98	1.979	1.979	1.977	1.974
	$10^4 \tan \delta$	—	—	—	—	—	—	—	—	3.1	6.0	9.4	12.2	13.2
250	κ	1.93	—	—	—	—	—	—	—	1.939	1.929	1.928	1.923	1.922
	$10^4 \tan \delta$	33.9	3.36	1.11	.60	.23	.6	—	1.3	4.5	7.2	10.3	11.2	12.5
150°	κ	2.01	—	—	—	—	—	—	—	—	—	—	—	—
	$10^4 \tan \delta$	13.6	1.71	.53	.40	.43	1.1	—	—	—	—	—	—	—
23°	κ	2.06	—	—	—	—	—	—	—	—	—	—	—	—
	$10^4 \tan \delta$	.06	.14	.23	.33	.71	1.5	—	—	—	—	—	—	—

*After heating to 250°C.

"TEFLON" FEP 100

E.I. Du Pont de Nemours & Company

Freq. Hz	23°C		75°C		100°C		150°C		23°C	
	κ	$10^4 \tan \delta$	$\kappa$	$10^4 \tan \delta$	$\kappa$	$10^4 \tan \delta$	$\kappa$	$10^4 \tan \delta$	$\kappa$	$10^4 \tan \delta$
10^2	2.06	1.21	-	-	2.03	6.01	2.00	32.3	2.06	1.49
10^3		.80	-	-	-	-		4.42		.43
10^4		.89	-	-	-	-		1.14		.13
10^5		2.43	-	-	-	-		1.25		1.72
5×10^5		4.59	-	-	-	-		1.59		3.85
10^6		5.30	-	-	-	-		1.73		4.95
1.5×10^6		5.8	-	-	-	-		-		5.4
2×10^6		5.9	-	-	-	-		-		-
3.5×10^6	↓	5.6	-	-	-	-		-	*	5.5
10^7	2.05	5.3	-	-	-	-		2.5	2.05	5.3
10^8	2.05	7.0	-	-	-	-		-	-	-
3×10^8	2.05	9.3	-	-	-	-		7.5	-	-
1×10^9	2.047	13.7	2.031	13.2	2.022	12.8	1.999	12.3	-	-
3×10^9	2.045	11.6	2.029	13.3	2.020	13.8	1.997	13.6	-	-
6.5×10^9	2.043	9.0	2.027	10.3	2.018	11.6	1.994	12.8	-	-
1.4×10^{10}	2.040	7.5	2.024	9.4	2.013	11.1	1.986	12.4	-	-
2.4×10^{10}	2.034	6.7	2.014	8.3	2.000	10.0	1.974	11.2	-	-

"VITON", at 24°C

E.I. Du Pont de Nemours & Company

Freq., Hz	κ	$\tan \delta$	$\gamma (\text{dcm} \cdot \text{cm})^{-1}$
31.4	10.76	.0547	1.01E-11
160	10.37	.0327	1.92E-11
1000	10.19	.0349	1.90E-10
10^4	9.39	.0910	4.23E-9
10^5	8.00	.148	6.54E-8
3×10^5	6.60	.198	1.61E-7
10^6	5.99	.212	7.04E-7
9.5×10^6	4.27	.194	4.36E-6
1.8×10^7	3.95	.176	6.96E-6
6×10^7	3.64	.160	1.70E-5
3×10^8	3.30	.0951	9.24E-5
1×10^9	3.171	.0725	1.37E-4
3×10^9	3.037	.0542	2.82E-4
8.5×10^9	3.03	.0372	5.25E-4

Standard Conditions

Teflon both sides	Sample No.	8.5 GHz		14 GHz		24 GHz	
		<	tan δ	<	tan δ	<	tan δ
Single ply	1	2.87	.0181	-	-	2.75	.0179
	2	2.94	.0179	-	-	2.82	.0147
	3	2.93	.0178	-	-	2.76	.0146
	4	2.86	.0174	-	-	2.86	.0148
	5	2.88	.0171	-	-	2.80	.0156
	6	2.76	.0172	2.80	.0181	2.8	.0176
	7	2.76	.0175	2.77	.0168	2.82	.0171
	8	2.73	.0174	2.75	.0164	2.77	.0188
	9	2.86	.0180	2.90	.0127	2.78	.0119
	10	2.85	.0132	2.84	.0122	2.87	.0105
2 Ply same	1	2.88	.0135	2.75	.0121	2.63	.0120
	2	2.88	.0121	2.85	.0126	2.84	.0121
	3	2.88	.0126	2.85	.0129	2.77	.0093
3 Ply same	1	2.88	.0118	2.83	.0121	2.69	.0090
	2	2.88	.0121	2.85	.0126	2.84	.0121
	3	2.88	.0126	2.85	.0129	2.77	.0093
4 Ply same	1	2.88	.0121	2.83	.0116	2.68	.0103
	2	2.89	.0122	2.82	.0112	2.71	.0068
	3	2.89	.0120	2.83	.0115	2.73	.0079
1 Ply uncoated	1	2.88	.0108	2.87	.0107	2.72	.0075
	2	2.93	.0104	2.87	.0098	2.75	.0089
	3	2.86	.0104	2.82	.0096	2.81	.0089

After soaking 25 hrs., distilled water both sides,
then samples punched and measured within two minutes

Teflon both sides	Sample No.	8.5 GHz		14 GHz		24 GHz	
		<	tan δ	<	tan δ	<	tan δ
Single ply	1	2.89	.0191	-	-	2.77	.0118
	2	2.91	.0192	-	-	2.88	.0144
	3	2.90	.0193	-	-	2.87	.0161
	4	2.87	.0189	-	-	2.83	.0160
	5	2.86	.0190	-	-	2.71	.0119
	6	2.77	.0192	2.81	.0191	2.71	.0195
	7	2.81	.0202	2.81	.0195	2.78	.0151
	8	2.88	.0198	2.84	.0194	2.79	.0164
	9	2.90	.0182	2.86	.0163	2.60	.0113
	10	2.92	.0163	2.88	.0164	2.78	.0119
2 Ply same	1	2.90	.0184	2.82	.0155	2.77	.0121
	2	2.92	.0184	2.82	.0155	2.77	.0121
	3	2.92	.0184	2.82	.0155	2.77	.0121
3 Ply same	1	2.91	.0163	2.83	.0154	2.80	.0109
	2	2.93	.0164	2.84	.0145	2.79	.0114
	3	2.92	.0167	2.93	.0167	2.80	.0117
4 Ply same	1	2.93	.0138	2.89	.0126	2.72	.0084
	2	2.96	.0143	2.80	.0123	2.79	.0087
	3	2.98	.0148	2.84	.0120	2.83	.0089

Cross-linked polystyrene

General Electric Company

Standard conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	2.54	2.539	2.535	2.535	2.535	2.531	$2.85 \pm .05$
$\tan \delta$	.00107	.00094	.00063	.00041	.00057	.00084	$.0015 \pm .0005$

After 48 hrs. 30/1 H₂O/NaCl solution

κ	2.54	2.544	2.540	2.538	2.537	2.535
$\tan \delta$	.00142	.00127	.00107	.00054	.00083	.00108

Noryl SE-1

General Electric Company

Freq., MHz	κ	$\tan \delta$
100	2.639	.00135
1000	2.635	.00292
3000	2.629	.00545

Noryl SE-1-802

General Electric Company

Standard Conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	2.71	2.706	2.699	2.696	2.691	2.69	$2.5 \pm .1$
$\tan \delta$	.0030	.00304	.00319	.00260	.00292	.0034	$.005 \pm .003$

After 48 hrs. 30/1 H₂O/NaCl solution

κ	2.71	2.708	2.705	2.70	2.696	2.69
$\tan \delta$	.0031	.00281	.00325	.0031	.0039	.00336

Noryl GFN3

General Electric Company

Standard Conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	3.12	3.11	3.10	3.09	3.08	3.06	$2.85 \pm .1$
$\tan \delta$	.0032	.0033	.0037	.00453	.0049	.0053	$.008 \pm .003$

Noryl GFN3 (cont.)

After 48 hrs. 30/1 H₂O/NaCl solution

Freq., GHz	.5	1	3	8.5	14	90
κ	3.13	3.13	3.11	3.10	3.08	3.07
$\tan \delta$	.0034	.0036	.0037	.0046	.0053	.0058

Silicone resin laminates

Supplied by Lincoln Lab., MIT

<u>Sample</u>	<u>Freq., GHz</u>	1	3	8.5
581 Astro Quartz	κ	2.27	2.20	2.28
" "	$\tan \delta$	.0015	.0011	.0014
E Glass	κ	3.33	3.42	3.38
	$\tan \delta$	.0028	.00403	.0075

Polyester + Al + C

MIT Bio-Medical

Polyester resin ('Laminac 4110, American Cyanamid) + 14.5%
(Bakelite purified Al powder) + various amounts of
acetylene black as indicated

Freq., GHz	1	3	8.5
0.24% C			
κ'	5.70	5.18	4.90
$\tan \delta_d$	.167	.122	.088
μ'/μ_0	1.02	.936	.942
$\tan \delta_m$	.037	.036	.032
0.48% C			
κ'	7.10	6.10	5.34
$\tan \delta_d$	.351	.239	.172
μ'/μ_0	1.036	.962	.937
$\tan \delta_m$	.023	.036	.030
0.96% C			
κ'	9.66	7.54	6.02
$\tan \delta_d$	.223	.188	.138
μ'/μ_0	1.04	.993	.921
$\tan \delta_m$	.023	.043	.046
1.9% C			
κ'	18.7	11.35	8.01
$\tan \delta_d$	.44	.361	.262
μ'/μ_0	1.04	.934	.984
$\tan \delta_m$	.021	.038	.061

L-600 Polymer

Monsanto

Zexp.	Hz	1	2	5	10	33.3	10^2	10^3	10^4	2×10^4	5×10^4	10^5
25°C 77°F	κ	4.23	4.20	6.17	4.11	.4.CJ	3.91	3.67	3.55	3.49	3.42	3.39
	$\tan \delta$	.0227	.0236	.0254	.0281	.0321	.0380	.0315	.0318	.0299	.0274	.0252
	Hz	106	107	1.8x10 ⁷	108	3x10 ⁸	10^9	3×10^9	8.52×10^9	2.4×10^{10}		
25°C	κ	3.29	3.21	3.19	3.15	3.11	3.10	3.0'	3.084	3.05		
	$\tan \delta$	.0163	.0107	.0099	.0087	.0073	.0072	.00695	.00629	.0083		
	Hz	33	100	333	1000	3333	10^4	10^5	10^6	10^7	10^8	
49.3°C 121°F	κ	4.36	4.26	4.13	4.004	3.86	3.74	3.54	3.39	3.30	3.13	
	$\tan \delta$	.0361	.0414	.0462	.0503	.0509	.0487	.0394	.0283	.0185	.0102	
	Hz	3×10^9	8.52×10^9	2.4×10^{10}								
	κ	3.11	3.10	3.06								
	$\tan \delta$	.0099	.0088	.0087								
	Hz	102	103	3333	10^4	2×10^4	10^5	10^6	10^7	10^8	3×10^9	8.5×10^9
75°C 167°F	κ	4.65	4.39	4.22	4.05	3.96	3.95	3.50	3.34	3.14	3.12	3.07
	$\tan \delta$	.0388	.0534	.0607	.0629	.0622	.0574	.0445	.0287	.0128	.0116	.0110
	Hz	102	103	10^4	10^5	10^6	10^7	10^8	3×10^9	8.5×10^9	2.4×10^{10}	
100°C 212°F	κ	6.08	5.46	4.87	4.29	3.82	3.48	3.21	3.15	3.12	3.10	
	$\tan \delta$	.0971	.0260	.0921	.0938	.0773	.050	.0232	.0172	.0141	.012	
	Hz	102	103	10^4	10^5	10^6	10^7	10^8	3×10^9	8.5×10^9	2.4×10^{10}	
125°C 257°F	κ	19.1	13.5	9.19	6.64	4.96	4.03	3.56	3.30	3.22	3.18	
	$\tan \delta$	.246	.273	.256	.222	.183	.119	.0617	.034	.027	.022	
	Hz	102	103	10^4	10^5	10^6	10^7	10^8	3×10^9	8.5×10^9	2.4×10^{10}	
150°C 302°F	κ	21.8	20.2	17.15	11.39	7.05	4.58	3.95	3.63	3.42	3.33	
	$\tan \delta$	.765	.139	.195	.299	.314	.206	.167	.109	.048	.037	
175°C 347°F	κ	31	22	19.6	18.4	13.8	8.20	4.19	3.88	3.55	3.42	
	$\tan \delta$	2.9	.55	.087	.094	.252	.368	.231	.59	.070	.051	

Moplen 004 polypropylene

Nevamont

T°C	Freq., GHz	1	3	Error limits for both freq.
25	κ	2.260	2.254	$\pm .005$
	$\tan \delta$	.00042	.00036	$\pm .00005$
100	κ	2.15	2.14	$\pm .03$
	$\tan \delta$	.00060	.00063	$\pm .00005$

Dialite 55 P687 laminate

Supplied by RCA

At 300 MHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-143	4.248	.00351	-15.5	4.333	.00594
-128.6	4.257	.00343	-6.8	4.339	.00550
-119	4.262	.00328	0.6	4.351	.00700
-110	4.266	.00338	14.1	4.362	.00743
-101	4.273	.00371	24	4.370	.00783
-89.5	4.289	.00397	25.6	4.373	.00790
-84	4.282	.00449	37.1	4.379	.00857
-47.6	4.309	.00499	47.1	4.383	.00889
-39.9	4.316	.00536	58.1	4.399	.00936
-34.5	4.322	.00507	68.6	4.312	.01015
-29.7	4.323	.00550	75.2	4.319	.0104
-23.2	4.328	.00586			

Fluorosint

Supplied by RCA

At 300 MHz

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-149	3.468	.00074 $\pm .0001$	-10.3	3.481	.00074 $\pm .0001$
-133	3.471		-13.6	3.482	
-124.1	3.473		-4.7	3.483	
-116.8	3.472		2.5	3.482	
-104	3.473		11.6	3.486	
-81.8	3.475		22.6	3.485	.00074 $\pm .06005$
-75.6	3.477		26.5	3.486	
-63.6	3.479		31	3.487	.00074 $\pm .0001$
-53.7	3.489		45.7	3.490	
-44	3.479		54.7	3.489	
-40.5	3.480		64.2	3.490	
-33.8	3.481		75.5	3.492	
-25.8	3.481				

G11 laminate

At 300 MHz

Supplied by RCA

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
76.7	4.849	.0238	- 40.8	4.453	.0094
68.2	4.812	.0228	- 50.2	4.431	.0088
58.8	4.771	.0218	- 60.	4.415	.0081
48.3	4.731	.0197	- 70.5	4.401	.0076
39.2	4.691	.0190	- 80.9	4.384	.0070
28.4	4.649	.0176	- 90.7	4.373	.0064
12.1	4.593	.0156	-100.6	4.363	.0056
6.8	4.572	.01485	-113.6	4.347	.00494
0	4.555	.0141	-121.1	4.338	.0046
-10.	4.524	.0126	-130.	4.332	.0043
-19.2	4.501	.0119	-140.3	4.322	.0041
-31.	4.472	.0107			

RTV-511, unloaded

At 300 MHz

Supplied by RCA

T°C	κ	$\tan \delta$	T°C	κ	$\tan \delta$
-146.1	3.202	.0109	- 30	3.409	.0118
-133.8	3.228	.0135	- 20.3	3.385	.0097
-122	3.248	.0154	- 8.1	3.364	.0080
-111	3.266	.0170	+ 1.7	3.347	.0071
-100.8	3.280	.0186	10.8	3.332	.0068
- 89.7	3.310	.0218	22.8	3.309	.00625
- 83.6	3.334	.0272	33.3	3.286	.0059
- 68	3.388	.0269	43.6	3.252	.0054
- 60.6	3.413	.0226	52.7	3.222	.0052
- 50.8	3.423	.0186	63.2	3.155	.00505
- 39	3.419	.0140	73	3.123	.0047

RTV-511, unloaded
At 2.2969 GHz

Supplied by RCA

T°C	K	tan δ	T°C	K	tan δ
-134.8	3.071	.00190	28.2	3.328	.0270
130	3.073	.00194	19.8	3.335	.0254
119.8	3.090	.0023	- 8.1	3.354	.0215
110	3.109	.0036	+ 2.5	3.324	.0183
98.2	3.142	.0062	12.3	3.309	.0160
89	3.171	.0093	21.8	3.295	.0143
80	3.197	.0130	32.7	3.273	.0124
69.3	3.228	.0178	43.1	3.236	.0112
60	3.254	.0224	52.7	3.194	.0103
50.2	3.281	.0264	64.8	3.145	.0091
41.1	3.307	.0286	72.9	3.133	.0085

RTV-511, 45 parts zinc oxide
At 300 MHz

Supplied by RCA

T°C	K	tan δ	T°C	K	tan δ
-128.9	3.546	.0036	20.1	3.832	.0108
117.4	3.580	.0061	+ 9.8	3.816	.0092
112.9	3.599	.0060	- 0	3.800	.0084
103.6	3.635	.0109	10.2	3.780	.0075
90	3.706	.0216	21.6	3.745	.0067
79.9	3.750	.0246	31.3	3.727	.0064
68.2	3.808	.0254	42.4	3.671	.0063
59.6	3.838	.0227	51.5	3.640	.00625
51.3	3.853	.0196	62	3.605	.0062
40.6	3.858	.0153	73.2	3.584	.0065
30.2	3.850	.0131			

RTV-511, 45 parts zinc oxide
At 2.2969 GHz

Supplied by RCA

T°C	κ	tan δ	T°C	κ	tan δ
131.2	3.395	.0072	-10.6	3.675	.0275
120.1	3.404	.0077	+ .6	3.666	.0243
111	3.413	.0082	10	3.654	.0221
99.7	3.445	.0099	21.3	3.636	.0196
90.2	3.479	.0134	26.6	3.623	.0183
81.6	3.514	.0171	32.8	3.608	.0172
69.1	3.557	.0236	35.3	3.600	.0168
60	3.587	.0278	45	3.578	.0160
49.7	3.617	.0314	56.2	3.553	.0152
40.6	3.642	.0324	65.2	3.528	.0146
30.5	3.667	.0318	74.7	3.501	.0142
21.2	3.676	.0299			

RTV-511, 90 parts zinc oxide
At 300 MHz

Supplied by RCA

T°C	κ	tan δ	T°C	κ	tan δ
-129.8	4.047	.0214	-19.3	4.118	.0098
-116.8	4.074	.0228	-10.3	4.102	.0086
-103.8	4.099	.0232	1.0	4.083	.00776
-90.2	4.122	.0218	6.7	4.073	.00750
-96.1	4.114	.0223	22.6	4.038	.00675
-78.9	4.132	.0204	33.8	4.008	.00638
-69.3	4.136	.0190	43.8	3.976	.00630
-59.7	4.140	.0169	52.9	3.948	.00645
-50.2	4.141	.0148	62.9	3.923	.00670
-39.9	4.138	.0130	72.5	3.907	.00732
-31.2	4.132	.0115			

RTV-511, 90 parts zinc oxide

Supplied by RCA

At 2.2969 GHz

T°C	κ	tan δ	T°C	κ	tan δ
-129.2	3.662	.0111	20.5	3.923	.0327
120	3.672	.0116	9.8	3.921	.0298
109.7	3.699	.0131	0	3.917	.0269
102.5	3.712	.0139	9.4	3.908	.0246
90.2	3.770	.0181	16.6	3.897	.0229
80.9	3.803	.0229	21.9	3.888	.0215
71.1	3.828	.0272	28.2	3.872	.0202
58.9	3.858	.0326	42.6	3.834	.0182
50.2	3.881	.0346	51	3.810	.0179
40.3	3.900	.0348	61.9	3.775	.0176
30.2	3.916	.0340	72.8	3.742	.0174

Polyurethane sealant P/N 596927

Supplied by Raytheon Company

<u>Average values</u>					
Freq., Hz	60	1 k	1 M	10 M	30 M
κ	7.05	6.81	4.71	4.02	3.69
tan δ	.0150	.0422	.102	.1135	.1106

At 1 kHz

T°C	κ	tan δ	T°C	κ	tan δ
22	6.81	.0422	90	5.72	.0101
30	6.73	.0324	100	5.57	.0140
40	6.62	.0209	110	5.45	.0196
50	6.46	.0145	120	5.34	.0285
60	6.31	.0104	130	5.21	.0391
70	6.12	.0083	140	5.06	.0568
80	5.90	.0086	150	4.84	.0762

Stycast 2651-40 RQ
(Emerson & Cumming)

Supplied by Raytheon Company

Sample No.	Freq., Hz	60	1 k	1 M	10 M	30 M
1	κ	5.09	4.92	4.22	3.96	3.82
	$\tan \delta$	.0305	.0231	.0452	.0435	.0515
2	κ	5.18	4.94	4.28	4.06	3.88
	$\tan \delta$	.0294	.0231	.0449	.0426	.050
3	κ	5.15	4.97	4.28	4.02	3.86
	$\tan \delta$	.0304	.0231	.0451	.0429	.0484
Average	κ	5.14	4.94	4.26	4.01	3.85
	$\tan \delta$	.0301	.0231	.0451	.0430	.050

Temperature runs, 1 kHz

T°C	1		2		3		Average	
	κ	$\tan \delta$	$\kappa$	$\tan \delta$	$\kappa$	$\tan \delta$	$\kappa$	$\tan \delta$
23	4.98	.0247	5.08	.0245	5.06	.0250	5.04	.0247
30	5.05	.0253	5.15	.0251	5.12	.0265	5.11	.0256
40	5.12	.0280	5.22	.0262	5.25	.0291	5.20	.0276
50	5.29	.0318	5.38	.0307	5.36	.0322	5.34	.0316
60	5.59	.0401	5.86	.0438	5.82	.0456	5.76	.0432
70	6.34	.0776	6.41	.0745	6.37	.0715	6.37	.0745
80	6.96	.0998	7.32	.0976	7.16	.0985	7.15	.0985
90	7.42	.110	7.54	.108	7.50	.109	7.49	.109
100	7.55	.157	7.66	.160	7.70	.162	7.65	.159
110	7.50	.282	7.65	.241	7.76	.255	7.63	.259
120	7.41	.468	7.48	.522	7.58	.450	7.49	.482
130	7.35	.838	7.47	.731	7.50	.685	7.44	.751
140	7.40	1.13	7.52	.948	7.32	.914	7.41	.964
150	7.32	1.18	7.43	.998	6.92	1.17	7.22	1.116
26			4.92	.0185				

Honeycomb laminate

Supplied by Rockwell International Co.

Skin, E||

T ^o F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	4.14	4.45	4.40
	$\tan \delta$	.010	.0120	.0160
-300	κ	-	4.35	4.33
	$\tan \delta$	-	.0022	.0025
-170	κ	-	4.40	4.37
	$\tan \delta$	-	.0095	.0080
400	κ	-	4.50	4.45
	$\tan \delta$	-	.018	.0205

Core (Nomex), E||

74	κ	1.1250	1.2305	1.1476
	$\tan \delta$	.00270	.01040	.00735
-300	κ	-	1.184	1.1315
	$\tan \delta$	-	.01500	.00150
-170	κ	-	1.1817	1.1400
	$\tan \delta$	-	.00266	.00470
400	κ	-	1.12986	1.12610
	$\tan \delta$	-	.00195	.00248

Composite, E||

		300 MHz	1 GHz	3 GHz
74	κ	1.4756	1.4484	1.4246
	$\tan \delta$	.00438	.00499	.00543
-300	κ	1.4283	1.4978	1.3893
	$\tan \delta$	.00095	.00087	.00174
-170	κ	1.4550	1.4410	1.4220
	$\tan \delta$	.00220	.00240	.00340
400	κ	1.4339	1.4102	1.3920
	$\tan \delta$	.00159	.000965	.00202

Nomex felt Supplied by Rockwell International Corp.

T ^o F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	1.21500	1.24400	1.30850
	$\tan \delta$	.00339	.00451	.00560
-300	κ	-	1.22390	1.25780
	$\tan \delta$	-	.00086	.00162
-170	κ	-	1.22460	1.27400
	$\tan \delta$	-	.00159	.00320
400	κ	-	1.23140	1.27280
	$\tan \delta$	-	.00634	.00516

Silicone RTV Supplied by Rockwell International Corp.

T° F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	3.59000	3.55000	3.50500
	$\tan \delta$	.01250	.01850	.021500
-300	κ	-	3.48000	3.63900
	$\tan \delta$	-	.003250	.00363
-170	κ	-	3.57000	3.57000
	$\tan \delta$	-	.01390	.01500
400	κ	-	3.48000	3.46100
	$\tan \delta$	-	.005370	.008970

Glastrate
(O-C Fiberglas) The Sippican Corp.

Freq., Hz	60	50 k	500 k	3 M	100 M
κ	1.450	1.432	1.417	1.405	1.398
$\tan \delta$	.0228	.0039	.0028	.0022	.0012

Infrared windows

Texas Instruments

TI-1173 and TI-20

8.5 GHz

Sample No.	T°C	K	tan δ
TI-1173	25	9.69 ± .08	.0008 ± .0005
TI-20	25	8.037 ± .04	.00046 ± .00008
	100	8.041	.00057 ± .00012

Diallylphthalate, glass

Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T°F	K	tan δ
C 1-2	-	77	4.91	.0087
			4.90	.0082
C 3-3	-	77	4.91	.0087
			4.88	.0073
C 5-6	1.4765	77	4.91	.0092
			4.91	.0081
	1.4884	189	4.89	.0117
	1.5347	400	4.85	.0297
	1.554	535	4.83	.0354
	1.4813	77	4.92	.0090

Modified, at 8.5 GHz

B 1-2	-	77	4.47	.0072
			4.45	.0071
B 3-4	-	77	4.45	.0072
			4.39	.0060
*B 5-6	1.4755	77	4.48	.0073
	1.4846	199	4.49	.0092
	1.5105	400	4.49	.0150
	1.539	539	4.41	.0195
	1.478	77	4.51	.0074

*No appreciable change when sample reversed and rotated 90 degrees.

Epoxy, glass

Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T° F	K	tan δ
R 1-2	-	77	5.03	.0196
			5.07	.0191
R 5-6	-	77	5.05	.0206
			5.07	.0203
* R 3-4	1.221	77	5.04	.0208
	1.240	240	5.03	.0260
	1.259	432	5.09	.0341
	1.299	636	5.17	.0228
	1.223	77	5.01	.0175

* No appreciable change when sample reversed and rotated 90 degrees.

Polybutadiene, glass

Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T° F	K	tan δ
A 1-2	-	77	4.42	.0080
			4.38	.0079
A 5-6	-	77	4.40	.0084
			4.41	.0082
A 3-4	-	77	4.39	.0083
			4.40	.0081
		200	4.39	.0086
		401	4.28	.0086
		561	4.29	.0088
		77	4.40	.0068

Polyurethane foam
At 300 MHz

Upjohn

2-lb. foam

Sample No.	T°C	K	tan δ
1-3	25	1.038	.00070
2-3	↓	1.038	.00072
3-3	↓	1.036	.00072
4-3	↓	1.036	.00074
1-2	↓	1.036	.00068
1-3 + 2-3	↓	1.040	.00068
	100	1.047	.00151

3-lb. foam

1	25	1.0524	.00109
2	↓	1.0535	.00110

Cyanurate ester resin

ASR-10500, at 8.5 GHz

Whittaker Corporation

	T°F	K	tan δ
As received	73	3.143	.00672
As received, reversed	73	3.142	.00668
In temperature holder	140	3.156	.00798
	201	3.171	.00975
	310	3.181	.0125
	400	3.191	.0137
	502	3.193	.0145
	102	3.121	.00668

Polybutadiene-Astroquartz 3.164-ii

Firestone PM502, at 8.5 GHz

Whittaker Corporation

	T°C	K	tan δ
As received	73	3.105	.00301
Reversed	73	3.117	.00379
Over quarter wavelength	73	3.072	.00207
Reversed	73	3.079	.00393
After cutting	73	3.102	.00206
Reversed	73	3.129	.00314
In temperature holder	86	3.098	.00178
	159	3.070	.00174
	199	3.063	.00160
	303	3.058	.00141
	391	3.057	.00137
	516	3.039	.00131
	72	3.088	.00164

Polybutadiene-Kevlar 3.164-10

Firestone PM502, at 8.5 GHz

Whittaker Corporation

As received	73	3.257-3.261	.9179-.0190
Reversed	73	3.254-3.258	.0176-.0185
Over quarter wavelength	73	3.231-3.230	.0162-.0170
Reversed	73	3.235-3.235	.0163-.0172
After curring	73	3.220-3.253	.0161-.0179
In temperature holder	74	3.188	.0154
	170	3.226	.0322
	211	3.225	.0262
	310	3.167	.0135
	417	3.062	.0117
	515	3.065	.0156
	116	3.762	.00565
	71	3.061	.00483

Polyether sulfone (dry sample)

Whittaker Corporation

SN 300-P, 24 GHz, 24°C

K	tan δ
3.06	.0108

Polyphenylquinoxaline resin

Whittaker Corporation

PPQ 401, at 8.5 GHz

	T°F	K	tan δ
As received	73	3.084	.00392
As received, reversed	73	3.047	.00384
in temp. holder	74	3.052	.00384
	154	3.068	.00481
	208	3.074	.00527
	303	3.045	.00604
	402	3.028	.00608
	505	2.994	.00576
	158	3.031	.00467

Polyphenylquinoxaline-Astroquartz

Whittaker Corporation

2256-16A, at 24 GHz

T°C	K	tan δ
23.5	3.31	.00128
70	3.31	.00149
120	3.29	.00158
176	3.28	.00158
221	3.27	.00158
260	3.15	.00189
112	3.31	.00158

Polyurethane foam (rigid)

Witco Chemical Co.

D.C. resistivity = 1.7×10^{15} ohm-cm at 25°C

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